INTERFEROMETRIC MEASURING DEVICE FOR MEASURING SHAPE

Background Information

The present invention relates to an interferometric measuring device for measuring the shape especially of rough surfaces of a measured object, having a radiation-producing unit emitting short-coherent radiation, a beam splitter for forming a first and a second beam component, of which the first is directed via an object light path to the measured object and the second is directed via a reference light path to a reflective reference plane, having a superposition element at which the radiation coming from the measured object and the reference plane are brought to superposition, and an image converter which receives the superposed radiation and sends corresponding signals to a device for evaluation, the optical path length of the object light path being changed relative to the optical path length of the reference light path.

Such an interferometric measuring device is known from German DE 197 21 842 C2. In the case of this known measuring device, a radiation-producing unit, such as a light-emitting diode or a superluminescent diode, emits a short-coherent radiation, which is split via a beam splitter into a first beam component guided over an object light path, and a second beam component guided over a reference light path. The reference light path is periodically changed, using two deflector elements and a stationary diffraction grating positioned behind it, by activating the deflector elements, so as to scan the object surface in the depth direction. If the object light path and the reference light path coincide, a maximum interference

contrast results, which is detected using an evaluation device post-connected to the photodetector device.

An interferometric measuring device representative of the measuring principle (white-light interferometry or short-coherent interferometry) is also specified in German DE 41 08 944 A1. Here, however, a moved mirror is used to change the light path in the reference ray path. In this method, the surface of the object is imaged on the photodetector device, using an optical system, it being difficult, however, to conduct measurements in cavities.

Additional such interferometric measuring devices and interferometric measuring methods based on white-light interferometry are described by P. de Groot, L. Deck, "Surface Profiling by Analysis of white-Light Interferograms in the Spatial Frequency Domain" J. Mod. Opt., Vol. 42, No. 2, 389-401, 1995 and No. T. Maack, G. Notni, W. Schreiber, W.-D. Prenzel, "Endoskopisches 3-D-Formmesssystem",(Endoscopic 3-D Shape Measuring System) in Jahrbuch für Optik und Feinmechanik, Ed. W.-D. Prenzel, Verlag (publisher) Schiele und Schoen, Berlin, 231-240, 1998 verwiesen (submitted).

In the case of the interferometric measuring devices and measuring methods named, one difficulty is making measurements in deep cavities or narrow ducts. One suggestion for a measuring device in which measurements can be performed even in cavities, using white-light interferometry, is shown in German DE 197 21 843 C1. It is proposed there to split a first beam component further into a reference beam component and at least one measuring beam component, an additional beam splitter and the reference mirror being positioned in a common measuring probe. To be sure, such a measuring probe can be introduced into cavities, however, using this device, in each measurement, only a small, dot-like location in the surface can be scanned. In order to take the measure of more locations on the surface in the depth direction, relative motion between

measured object and measuring probe is required, an exact lateral coordination, however, being costly and difficult.

The object of the present invention is to make available an interferometric measuring device, of the kind mentioned at the outset, which especially makes possible simplified measurements in deep cavities with great accuracy.

This object is achieved by the features of Claim 1. According to this it is provided that an optical probe in the object light path, having an optical device for generating at least one optical intermediate image, be provided.

Similarly to an endoscope or a borescope, in using the optical device, because of the intermediate images, it becomes possible to image the observed surface, besides using high longitudinal resolution, also at high lateral resolution over a path which is long compared to the diameter of the imaging optics. For example, the optical probe can be introduced into the bores of valve seats or into vessels of organisms for the purpose of medical measurements. In contrast to the usual endoscope, quantitative depth information is now obtained. In this connection, an advantageous embodiment is one in which the at least one intermediate image is generated in the object light path. For this, the same optical device is used for illuminating the measured location on the measured object as for transmitting the radiation coming from the measured object to the photodetector device, if it is provided that both the radiation going to the measured object and the radiation coming back from it pass through the optical probe.

The optical image on the photodetector device can be improved by providing, in the reference light path, an equal, further optical probe or at least a glass device for compensating for a glass proportion present in the optical probe with regard to the elements for the intermediate image(s).

A favorable construction, as far as handling is concerned, is one in which the optical motion difference between the first and the second arm is greater than the coherence length of the radiation; the radiation coming from the first mirror and the reflecting element are guided through a common optical probe (common path) using a further radiation portion; in the optical probe, a reference mirror is arranged at such a distance from the measured object that the motion difference between the first mirror and the reflecting element is canceled, and one part of the radiation incident on the reference mirror is reflected to the photodetector device and one part is allowed to pass through to the measured object and is reflected from there to the photodetector device. A further benefit of this design is that the object and reference waves pass through virtually the identical optics assembly, so that aberrations are substantially compensated for. Moreover, this set-up is more resistant to mechanical shocks. In this connection, two embodiment possibilities are for the reference mirror to be provided on a flat face-plate or on a prism.

In this connection, handling can further be simplified by arranging a fiber optic element between the beam splitter and the further beam splitter.

In this design too, splitting essentially into a probe part and a part having a modulation arrangement is realized, handling being also favored.

The present invention is elucidated in the following on the basis of exemplary embodiments, with reference to the drawings. The figures show:

Figure 1 a first exemplary embodiment of an interferometric measuring device having an optical probe in a measured light path.

Figure 2 a second exemplary embodiment in which an optical

probe is provided both in the measured light path and in the reference light path.

Figure 3 a design of the interferometric measuring device having a common reference and measured light path.

Figure 4 a further exemplary embodiment in which, compared to Figure 3, fiber optics are provided between the first and a further beam splitter.

Figure 5 a further design example of the interferometric measuring device.

Figure 1 shows an interferometric measuring device having a radiation-producing unit SLD emitting short-coherent radiation, as, for example a light-emitting diode or a superluminescent diode, whose radiation is split by a beam splitter ST1 into a first beam component T1 of a measured light path and a second beam component T2 of a reference light path. The design is like that of a Michelson interferometer. In the reference light path, the second beam component is reflected by a reference plane in the form of a reference mirror RSP, the reference light path being periodically changed by moving the reference mirror RSP or by acoustooptical deflectors, as described in German DE 197 21 842 C2, mentioned at the outset. If the change of the light path is performed using two acoustooptical deflectors, a mechanically moved reflecting element becomes unnecessary, but instead, a fixed element, particularly a diffraction grating, can be used. By using a glass block G, the dispersion of an optical probe OSO arranged in the object light path can be corrected as necessary.

In the object light path, the radiation is coupled into optical probe OSO, so that the radiation illuminates the surface to be measured of measured object O. The surface of the object is imaged by optical probe OSO via one or more

intermediate images on photodetector equipment in the form of an image converter or image sensor BS, for instance, a CCD camera. The image of measured object O on image sensor BS is superposed with the reference wave of the second beam component. A high interference contrast occurs in the image of measured object O when the path difference in the reference light path and the measured light path is less than the coherence length. With regard to this, the measuring principle is based on white-light interferometry (short-coherent interferometry), as is described in greater detail in the documents mentioned at the outset. The length of the reference light path is varied over the entire measuring range for scanning in the depth direction of the surface to be measured, the length of the reference light path being detected for each measured point at which the greatest interference contrast appears. It is made possible by the intermediate images to image the surface of the measured object at a high lateral resolution over a range that is large compared to the diameter of the imaging optics. Optical probe OSO resembles an endoscope and a borescope, however, the illumination and the feedback of the radiation coming from the measured surface via the same optical device occurring via at least one intermediate image. Figure 1 shows schematically some lenses L as further imaging elements. The actual intermediate images are created in optical probe OSO.

For applications, in which an exact compensation for the influence of the imaging lenses of optical probe OSO is required, the same optical probe OSR is also integrated in the reference light path or reference arm between beam splitter ST1 and reference mirror RSP as in the object light path between beam splitter ST1 and measuring object O, as shown in Figure 2.

In a modified design according to Figure 3, the interferometric measuring device may also be realized as a device having common reference and measuring arms (common path

device). The interferometric measuring device is again illuminated by a short-coherent (broadband) radiation-producing unit. Beam splitter ST1 splits the light in two arms into first beam component T1 and second beam component T2, first beam component T1 falling on a first, fixed mirror SP1, and second beam component T2 falling on reflecting element RSP in the form of a reference mirror.

The optical path difference between the arms thus formed is greater than the coherence length of the radiation produced by radiation-producing unit SLD. Starting from the two mirrors SP1 and RSP, the reflected radiation is fed to optical probe OS via beam splitter ST1 and a further beam splitter ST2. The special quality of this design is that there is a reference mirror RSP2 in optical probe OS itself.

A part of the radiation is reflected by this reference mirror RSP2, while the other part of the radiation illuminates the surface to be measured. Reference mirror RSP2 may be mounted on flat face-plate or on a prism. By using a prism, the wave front of the radiation illuminating the object surface, i.e. of the object wave can be adapted to the geometry (e.g. inclination) of the surface to be measured. With the aid of optical probe OS, measured object O is in turn imaged via one or more intermediate images on image sensor BS, and superposed by the reference wave. In order to obtain height information, reflecting element RSP is made to traverse the measuring range, or changing the light path is undertaken as described above. In the image of measured object O great interference contrast appears when the path difference between fixed mirror SP1 and reflecting element RSP or of the light paths of the two arms is exactly the same as the optical path difference between reference mirror RSP2 and measured object O. In order to obtain the height profile, known methods for detecting the greatest interference contrast are used in each image point (pixel). The benefit of this design is that the object and reference waves pass through virtually the identical optics

assembly, so that aberrations are substantially compensated for. Moreover, this set-up is more rugged and, therefore, less susceptible to mechanical shocks.

For even simpler handling of the measuring device, the radiation of beam splitter ST1 can also be transmitted to further beam splitter ST1, using fiber optics LF, as is shown in Figure 4.

A further alternative design is shown in Figure 5. As an alternative to the design having the common reference path and measuring light path as in Figures 3 and 4, a combined Mach-Zehnder-Michelson arrangement is provided. Again, a broadband radiation-producing unit SLD is used, whose radiation is coupled into a fiber optic element. First beam splitter ST1 splits the radiation into an object arm OA and a reference arm RA. In object arm OA, first beam component T1 is coupled out of the corresponding light conducting fiber and coupled into optical probe OSO via further beam splitter ST2, so that the surface to be measured of measured object O is illuminated. The object surface is imaged by optical probe OSO via one or more intermediate images on image sensor BS. In reference arm RA light is coupled out of the corresponding light-conducting fiber, is then propagated, if necessary, through the same optical probe OSR as is applied in object arm OA, and is coupled in by a second fiber coupler R2 to a light-conducting fiber positioned there. The reference wave reaches further beam splitter ST2 via the light-conducting fiber. There it is uncoupled and superposed with the object wave on image sensor BS via further beam splitter ST2. In both arms, the optical paths in the air, in optical probes OSO or OSR as well as in the light-conducting fibers have to be adjusted. Tuning of the path lengths in reference arm RA is performed here, for example, by shifting second fiber coupler R2, so that the optical air path in the reference arm is changed.